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# Engineering Note

**Date:** June 13th, 2005
**Rev Date:** June 13th, 2005

**Project:** Dzero Electrical Support
**Doc. No:** A1050613A

**Subject:** Fusing of Calorimeter Pre-amplifier low voltage wiring

## Introduction

Recent repair activity inside the Dzero detector has resulted in the installation of fuses in the Cal Preamp ‘Y’ harnesses that have greater amperage ratings than those originally installed. This was not discovered until after the preamp area was closed, the detector irons moved and operations reinstated. The purpose of this note is to describe the situation as it now exists and to determine if the existing scenario constitutes a safety violation necessitating immediate redress.

## Description of the System

The Dzero Cal Preamp power supply system consists of two independent power supply units (the ‘primary’ and the ‘secondary’) that supply energy to a set of Cal Preamp boards. This system is replicated twelve times to instrument the entire calorimeter. The two supplies are each sized to handle the entire load and are connected in a ‘diode-OR’ configuration such that current cannot flow from one supply into the other, but both can supply current to the load. This is illustrated in Figure 1.

Each output of each supply is locally fused. Two sub-harnesses run from each power supply to a plate mounted behind the supplies where the two sub-harnesses fuse into a single harness. This area is called the ‘Y’-connect. At the ‘Y’-connect a third fuse is located for each voltage whose purpose is to protect the section of wiring from the ‘Y’-connect up to the preamplifier box should a short develop within the preamplifier box. The supplies generate eight output voltages at various currents. The supply ratings for each output and typical actual currents are given in Table 1. The ‘typical’ current ratings are taken from a snapshot of actual currents from the detector taken on June 13, 2005.

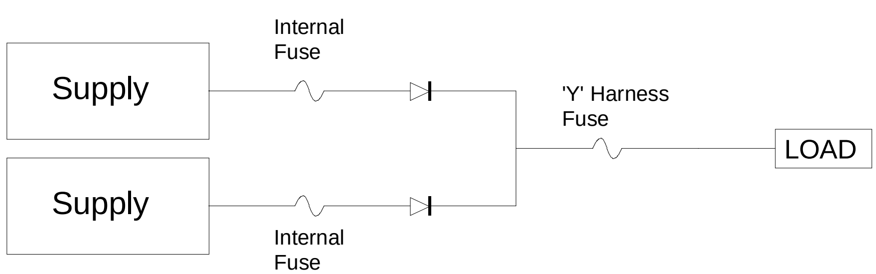


**Figure 1**

| Supply Name | Supply Voltage | Supply rating | Internal trip current | Typical current | Internal Fuse | ‘Y’ harness Fuse |
|---|---|---|---|---|---|---|
| A | +12V | 24A[1] | | 16.7A | 25A[2] | 20A[3] |
| B | +12V | 24A | | 15.81A | 25A | 20A |
| C | +8V | 25A | | 17.74A | 25A | 20A |
| D | +8V | 25A | | 17.31A | 25A | 20A |
| E | +8V | 25A | | 17.42A | 25A | 20A |
| F | +8V | 25A | | 17.25A | 25A | 20A |
| G | -6V | 30A | | 23.43A | 30A | 20A |
| H | -6V | 30A | | 23.11A | 30A | 20A |

**Table 1**

## *Details of the ‘Y’ Harness*

Each of the eight supply voltages listed in Table 1 are brought to the ‘Y’ harness from both primary and secondary supplies using 10AWG wire. There is no safety concern here as 10AWG is considered sufficient for currents up to 30A. It is on the output side of the ‘Y’ harness where concerns have been raised. The eight voltages are tied in pairs to fuses and the output (load) sides of the fuses are run using 12AWG, 105ºC wire. The lesser ampacity of 12AWG is the rationale behind the use of 20A fuses in the ‘Y’ harness.

The different voltages are split differently in the ‘Y’ harness. Each of the four +8V supply outputs are connected in turn to a single fuse at the ‘Y’ and a single 12AWG wire comes out of that fuse. The two +12V supply outputs are each connected to a *double* fuse and a single 12AWG wire comes out of *each* fuse. The same double-fuse arrangement is also used for the +6V output. This arrangement is caused by the four-column design of the preamplifier box. Each column has its own independent +8V supply and independent wire. Each column has independent *wires* but supplies are *shared* between two columns for the +12V and +6V distributions, as shown in Figure 2.

This modifies the load calculations for the +8V and +12V cases because the excessive current caused by a fault in one column adds to the normal current of a working column. A fault insufficient to blow the 20A fuse in the ‘Y’ harness may still blow the fuse internal to the supply because the *sum* of the currents in the two 12AWG wires exceeds the rating of the internal fuse.

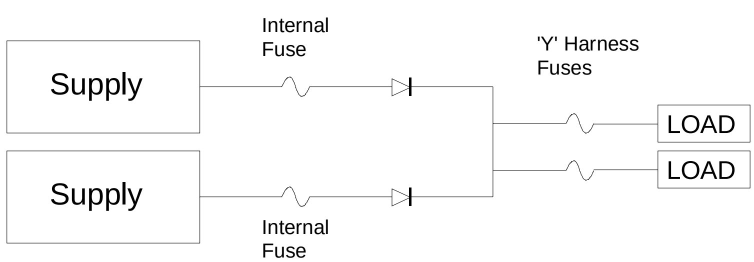


**Figure 2**

[1] Supply ratings determined from documentation at http://www-d0.fnal.gov/hardware/cal/lvps_info/preampps/default.html.

[2] Internal fusing determined from documentation at http://www-d0.fnal.gov/hardware/cal/lvps_info/preampps/preampacpwrdistupgradefull.pdf.

[3] ‘Y’ harness fuse ratings determined from documentation at http://www-d0.fnal.gov/hardware/cal/lvps_info/preampps/schematics/ed330277.pdf.

## Description of the incorrect installation

Recently one of the 20A fuses in the 'Y' harness for +8V blew, resulting in the loss of one column's worth of Calorimeter Preamp boards. In order to fix the problem a lengthy controlled access into the collision hall was required, including opening the magnet irons and ramping down the solenoid magnet. Upon review, after everything was closed up and the detector was operating again, it was revealed that a 25A fuse was used to replace the burnt out 20A fuse. The reason for the opening of the 20A fuse in the first place is unknown. Speculation from the staff is that operation of the fuse for long periods at 85% or so of rating may prematurely age the fuse, causing it to open at a lower current than its rating.

The speculation given is not supported by manufacturer's data sheets. The more likely explanation is a reduction in fuse lifetime from heating, either of the fuseholder or from IR drop in the wiring itself. A typical derating curve for fuses of the fast-blow and slow-blow type is given in Figure 3. Although most people assume that slo-blo fuses are preferred, they do have significantly larger temperature sensitivity.

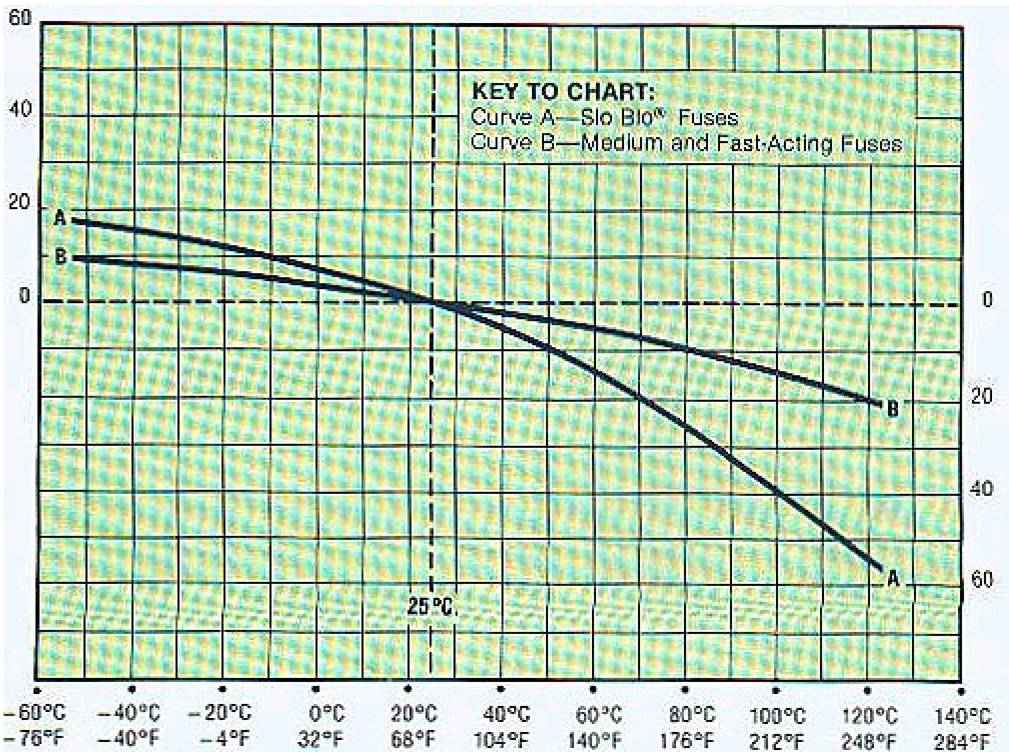


**Figure 3**

## +12V Fault analysis

Each of the two +12V supplies typically provides about 16A of current, which is split among two 12AWG wires (each feeding one preamp box column). The 16A is expected to split evenly between the two columns as the number of cards per column is constant. If a resistive short occurs in one column but not the other, the supply internal fuse should act to protect the wires when the total current is 25A. Allowing 8A for the un-shorted side, this would limit the current in the fault to 17A. The problem occurs if both the primary and secondary power supplies are enabled at the same time. In this situation, a total of 50A is available, allowing the current in the faulted column to rise as high as 42A before a supply's internal fuse would act. 42A is well in excess of the 20A current rating for 12AWG and necessitates the 20A fuse in the 'Y' harness.

Secondary protection is provided by the current trip designed into the monitor board of the supply. Divider resistors and the in-line current shunt (as described in the available documentation) set a maximum total current of 20.09A out of either the primary or the secondary supply. This further limits the available current in the wire from 42A down to 32A in the fault state when both supplies are on, but this is still in excess of the wire ampacity.

## +6V Fault analysis

The same analysis applies to the +6V supplies as applies to the +12V supplies. All supply parameters are identical.

## +8V Fault analysis

Without parallel wires, the situation for the +8V supply is a little simpler. Even with only one of the two supplies enabled, the internal fuse of the supply will not act until the current is in excess of the ampacity of 12AWG. Therefore, the 20A fuse in the 'Y' harness is required at all times. However, the secondary protection is set to the ampacity limit of the wire. If it can be proven that the secondary protection is sufficient to protect the 12AWG wire in any cases where the current drawn by the fault is in excess of the ampacity rating of 20A but less than the supply internal fuse rating of 25A, it may be possible to allow variation or elimination of the 20A fuse in the 'Y' harness *if and only if a fail-safe mechanism can be implemented to insure that only one supply at a time can ever be on.*

The secondary protection circuit is based upon a current shunt that develops a voltage proportionate to the current delivered by the power supply. A plug-in "personality module" uses a voltage divider of an internally developed 10V voltage to set a reference voltage used in an amplifier/comparator circuit. The failure analysis here is straight-forward.

- If the personality module is knocked loose or otherwise fails to make contact, the supply will trip, as shown from experience.
- In the odd case where one resistor of the personality module is somehow broken to remove the divider, the maximum current limit rises to 25A from 20A.
- Failure of the op-amp/comparator circuit of the motherboard does not guarantee a logic low signal will be sent to the CPLD of the motherboard as there is no pulldown resistor.
- If the monitor board power supply fails, there is no pulldown resistor on the 'VicorEnb' signal in the motherboard that allows the power supplies to operate. Experience with other Vicor supplies such as the AFE power supply show that the lack of signal is interpreted by the Vicor as 'OK'; an active pulldown is required to insure the supplies are OFF.

The unfortunate conclusion is that, while useful, the secondary protection is by no means fail-safe and therefore it is possible in the case of a dual fault (resistive short in load plus failure of secondary protection) for *a single* supply to drive a current greater than 20A but less than 25A into the AWG12 wire.

## Examination of likely temperatures in the Cal Preamp 12AWG harness

Given that the harness is a loose bundle of wires with unknown airflow, exact calculation is impossible. However, we can make a few educated guesses. The hottest wire in the harness likely experiences a $\theta_{wa}$ (wire-to-ambient) on the order of 200 degrees C per watt per square inch (estimate based on 8 times usual value of 25 for single components/wires). 12AWG typically has a resistivity of 0.00165 ohms/ft. The length of the 12AWG wires in the harness is about four feet; therefore a resistance of 0.0066 ohms is expected. At a current of 17 Amps the power dissipated is I * I * R, or 1.9 Watts.

The cross-sectional area of 12AWG is 0.0051 $in^2$, giving a radius of .040 in. This leads to a circumfrence of 0.253in, or a total radiative area of 12.15 $in^2$. We therefore expect the 12AWG wires to be about 31 degrees C above ambient. Earlier measurements by Dave Huffman showed that at a current of 25A in a bundle of eighteen 12AWG wires, the center conductor rose approximately 65 degrees C above ambient. Using the numbers above the estimate would have been a rise of 67 degrees C over ambient.

At this temperature rise a slow-blow fuse may be derated as much as 15%, meaning that the 20A fuse actually acts like a 17A fuse. This is so close to the actual measured currents of the supply that it may explain the consistent fuse failure rate. Use of a fast-blow 20A fuse would result in a derated value of 19 Amps. This simple change may possibly solve the problem of consistent fuse loss without having to re-examine the safety aspects.

In the problem of the moment, where a 25A fuse has been incorrectly installed, the estimated temperature of the wiring for a fault that draws 25A (just short of blowing the fuse) is expected to raise the temperature of the wire to something on the order of 90 degess C. This is within the temperature rating of the wire installed (105 degree).

## Hazard Mitigation via monitoring and/or administrative control

The current administrative controls in place at Dzero (per e-mail from Norm Buchanan in June 2005, and copied at the end of this document) indicate that the shifters are regularly required to look at currents and verify that no software error has caused both primary and secondary supplies to be enabled at the same time. A similar suggestion from Dean Schamberger points out that the experiment monitoring system could set a run-pausing severe error alert at any time software determines via status readback that a primary supply and its associated secondary supply are both on.

Laudable as these actions may be, they do rely on humans and/or software, both of which are considered too fallible to be a primary line of defense against a hazardous condition. None the less, the reader is reminded that the hazard for the +12V and +6V supplies does require the *dual* failure of both a circuit fault *and* the procedural fault of having both primary and secondary supply simultaneously energized. Therefore, these measures are a prudent addition to guard against this path to danger.

Unfortunately neither of these suggestions provides any additional security against a fault in the +8V supplies, and this is the root problem that requires the continued use of the correct fuses in the 'Y' harnesses.

## Conclusions

1. The 20 Amp fuses in the 'Y' harness are necessary to protect the 12 AWG wires of the harness in fault conditions and are appropriately sized.
2. Additional administrative and/or software controls can lessen the risks associated with the +12V and +6V supplies but, due to variance in wiring architecture, add no security against faults in the +8V supplies.
3. Temperature rise estimates suggest that the use of slo-blo fuses is a mistake and that, if usable, fast-blow fuses will provide greater margin against heat derating.
4. Because the 20A fuses are appropriate and necessary, use of larger fuses cannot be supported unless additional safety measures such as continuous temperature monitoring of the 12AWG wire bundles using klixons or similar hardware are implemented.
5. The incorrectly installed oversize fuses need to be removed and replaced with correctly sized fuses, or larger size wires installed to render the 'Y' harness fuses un-necessary.

## Appendix – email from Norm Buchanan

| | |
|---|---|
| Date sent: | Fri, 10 Jun 2005 17:07:51 -0500 |
| From: | Norm Buchanan <buchanan@fnal.gov> |
| Subject: | Administrative control |
| To: | janderson@fnal.gov |
| Copies to: | George Ginther <ginther@fnal.gov>, Norm Buchanan <buchanan@fnal.gov> |

Hi John,

I have sent an email to the CALMUO shifters and CAL experts regarding the precautions that must be taken to ensure that a primary and secondary preamp supply for one crate not be powered up simultaneously. I have CC'd a copy of this email to you, and to George. I have also posted a copy of this email on the CAL console in the control room. In addition I have talked personally with both Dean and Kirti, who will be my replacement next week, about the current situation. They are aware that they will be contacted if a preamp power supply is in need of a reset or power cycle. I believe that sufficient administrative action has been taken to ensure safe operation of the calorimeter in our current configuration.

Cheers,

N.